Fundamentals of Process-Based Cost Modeling

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Session Goal & Outline

- **Goal:**

  Understand the basic steps necessary to create a process-based cost model used to educate strategic technology choices

- **Topics Covered**
  - –Define Question to be Answered
  - –Identify Relevant Cost Elements
  - –Diagram Process Operations & Material Flows
  - –Relate What is Known to Cost
  - –Understand Uncertain Characteristics

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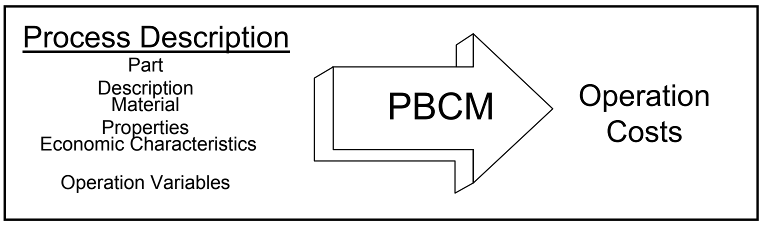
Review of Process-Based Cost Model (PBCM)

- **Objective**
  - **Map From Process Description To Operation Cost**
- **Purpose**
  - **Inform Decisions Concerning Technology Alternatives BEFORE Operations Are In Place**



What is a PBCM?

- **What is a PBCM?**
  - **Incorporates Technical Information About Process**
  - **Builds Cost Up From Technical Detail**
  - **Must Be Able To Address Cost Implications Of Change In**
    - *Product Design or*
    - *Process Operation -- Including Production Volume*
- **Remember:**
  - **The Purpose Of A Cost Model Is To Inform Technical Decisions**

Model Objective

- **Operation Cost**
  - –**Cost is generally measured as one of two rates**

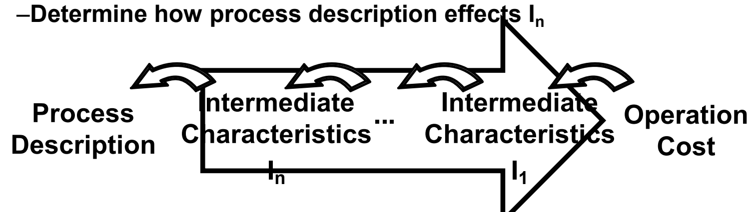
C^u — per unit

C^t — per time period

  - –**In Most Cases, Cost Per Unit (e.g., $ / part, $ / kg) Is The First Measure To Use For Comparing Technologies**

Creating a PBCM: Overview

- **Models are created by decomposing problem from cost backwards**
  - –**Determine what characteristics, I_1, effect cost**
  - –**Determine what characteristics, I_2, effect I_1 ... and so on until...**
  - –**Determine how process description effects I_n**



- **Model works from inputs to costs**

  <> Modeler works from costs to inputs

Creating a PBCM: Critical Steps

- Define Question To Be Answered
- Identify Relevant Cost Elements
- Diagram Process Operations & Material Flows
- Relate Cost To What Is Known
- Understand Uncertain Characteristics

Creating a PBCM: Step One

- Define Question To Be Answered
  - Cost of What?
    - *Carefully Understand Processing Boundaries*
  - Cost to Whom?
    - *Perspective Determines Pertinent Costs*
  - Cost Varying How?
    - *What Technical Changes Are Being Considered?*
  - Cost Compared to What?
    - *Relative to Other Options*
    - *Absolute Measure of Operation*
- More Than Any Physical Measure, Cost Is Fully Dependent On Context
    - Cost estimation requires exhaustive definition of context

Creating a PBCM: Step Two

- **Identify Relevant Costs**
  - –**Pertinent to Decision**
  - –**Necessary for Completeness / Credibility**

Common Elements of Manufacturing Cost

Material	Tooling
Energy	Overhead
Labor	Building
Equipment	Transportation
Marketing	Packaging
Advertising	Insurance

Exclude Unimportant Elements →

Common Relevant Cost Elements

Material	Tooling
Energy	Overhead
Labor	Building
Equipment	~~Transportation~~
~~Marketing~~	~~Packaging~~
~~Advertising~~	~~Insurance~~

Common Relevant Cost Elements

- **Variable**
  - –**Materials (Raw Materials & Consumables)**
  - –**Labor**
  - –**Energy**
- **Fixed**
  - –**Equipment (including Maintenance)**
  - –**Tooling**
  - –**Building**
  - –**Overhead**

- **Begin With These, But Always Ask Whether Others Are Important**
  - ***Tradeoff Amongst Time, Resources, and Available Knowledge***

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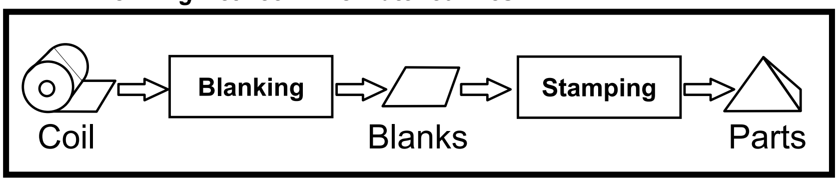
Creating A PBCM: Step Three

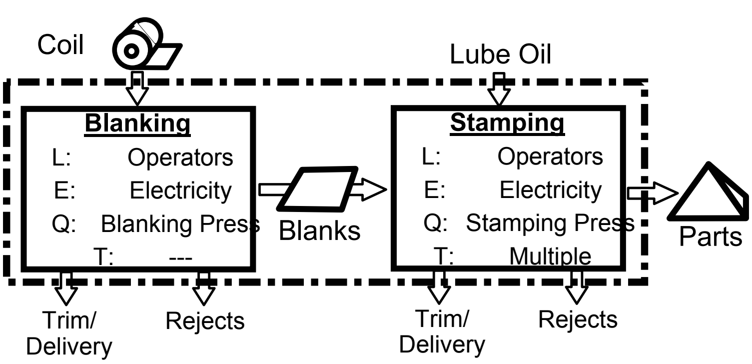
- Diagram Process Flows
  - Draw In Materials Flowing Into AND Out Of
  - Catalog For Each Process Step
    - *Equipment*
    - *Labor*
    - *Energy*
- e.g., Sheet Metal Stamping
    - *Forming Between Two Matched Dies*



Diagramming Flows Example: Stamping

- Catalog For Each Process Step

-- Equipment *-- Labor* *-- Energy*



Step Four: Relate Costs to What is Known

- Process Involves Four Steps
  - 1. Begin At The Current Endpoint (initially, the costs)
  - 2. Ask: How Can That Quantity Be Broken Down?
    - *Initially, How Many Do I Need x How Much Does Each Cost*
  - 3. Analyze Required Information (i.e. parameters)
    - *Are Those Parameters Acceptable Endpoints?*
    - *Can I (the model) Derive Them From A Simpler Or More Relevant Set Of Information?*
  - 4. If No, Repeat 1 With New Endpoints
  -
- Watch Out For Interdependent Parameters
    - *e.g. Part Mass & Part Dimensions*

Step Four Example

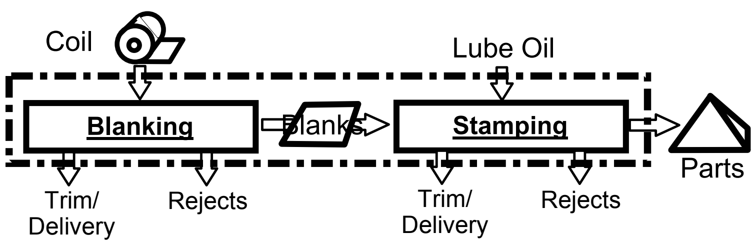
- Start At The End
  - What Is The End? Costs

Material	Equipment
Energy	Tooling
Labor	Overhead
	Building

- Pick An Endpoint
  - For Example, Material Cost For Blanking
- How Can That Be Broken Down:
  - How Many Do I Need x How Much Does Each Cost
  - Number of Coils Used x Cost per Coil

Step Four Example (cont.): Material Cost

- **Start At The End:**
  - **How Many Are Needed x How Much Does Each Cost**
    - ***Think In Terms Of Yearly Quantities***



Two Important Quantities

- **Production Capacity =**
  Quantity of "Good" Parts Capable of Being Produced
  - **How much CAN a plant produce**

- **Production Volume =**
  Quantity of "Good" Parts Produced
  - **How much DOES a plant produce**

- **Generally, Both Are Measured In Units Per Year**
  (e.g., parts / year, kgs / year)

Step Four Example: Material Cost (Blanking)

- Satisfactory Endpoints
  - **Production Volume (PV)**
  - **Coil Mass**
  - **Coil Price ($/kg)**

- **Material Cost (Blanking) =**
  Cost of Coils - Value of Scrap Sold
  - *Tip: Compute costs on annual basis, use PV to convert to unit cost*
- **$ of Coils = How Many X How Much Each Cost**
  Coils / Year X Unit Price of Coil
  - *Are these satisfactory endpoints? No: **Coils / Year**, depends on PV **Price of Coil**, normally prices are appropriate inputs, but this price is depends on the dimensions of the coil*
  - **Price of Coil = Mass of Coil X Price of Coil Material ($ / kg)**
    - *Satisfactory? Both seem like reasonable inputs*

Material Cost Blanking - 2

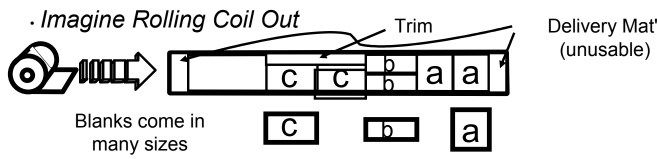
- Satisfactory Endpoints
  - **Production Volume (PV)**
  - **Coil Mass**
  - **Coil Price ($/kg)**
  - **L_c, W_c**
  - **Unusable Length**
  - **L_B, W_B**

Coils / Year = f (Blanks per Coil, Number of Blanks Made)
= (Blanks Produced / Year) ÷ (Blanks / Coil)

- *Satisfactory?* *Blanks / Year is dependent on PV*
- *Blanks / Coil depends on coil size*
- *Need more modeling*

Blanks / Coil = f(Usable Area on Coil, Blank dimensions)

- *Imagine Rolling Coil Out*



***# blanks* = f($Length_{coil}$, $Width_{coil}$, Unusable Length, $Length_{blank}$, $Width_{blank}$)**

Material Cost Blanking - 3

- **Satisfactory Endpoints**
  - **Production Volume (PV)**
  - **Coil Mass**
  - **Coil Price ($/kg)**
  - **L_c, W_c**
  - **Unusable Length**
  - **L_B, W_B**
  - **Reject Rate (R)**

- **Blanks Produced / Year = Good Blanks + Rejects**
- **effective $PV_{Blanking}$ = $PV_{Blanking}$ + Rejects**
  - *Can model **Rejects** as % of total production*
-
- **$effPV_B = PV_B + R \times effPV_B$**
- **$effPV_B = PV_B (1 - R)$**
  - *But what is **PV_B**?*
  - *Assume that **PV_B** equals Total Stampings Produced / Year (i.e., **$effPV_{Stamping}$**)*
- **$effPV_i = effPV_{i+1} (1 - R)$**
- *For last step, substitute **PV** for **$effPV_{i+1}$***

Material Cost Blanking - 4

- **Satisfactory Endpoints**
  - **Production Volume (PV)**
  - **Coil Mass**
  - **Coil Price ($/kg)**
  - **L_c, W_c**
  - **Unusable Length**
  - **L_B, W_B**
  - **Reject Rate (R)**
  - **Scrap Price**
  - **$thickness_B$**

- **Value of Scrap = Quantity of Scrap X Price of Scrap**
- **Quantity of Scrap = Mass of Coils Purchased**
- **Mass of Good Blanks**
  - *We know Mass of Coils*
  - *Need Mass of Good Blanks. Know Number of Good Blanks, Need Mass of Blanks*

  *Given blank length and width, only need **$thickness_{Blank}$***
- **Given This Set Of Information We Can Calculate The Annual Material Cost For Blanking**
  - *Remember, convert ot unit cost by dividing by **PV***

Capital Cost

- Capital Cost: One of the so-called "Fixed" Costs
  - –"Fixed" in that the firm incurs the cost irrespective of whether ANY products are manufactured
  - –Cannot merely acquire more of a fixed cost "factor" on a short time cycle

- Thus, fixed costs must be covered no matter how many units are actually produced

- Typical Capital Costs
  - –Machinery, Tools Employed
  - –Buildings , Fixed Contracts

Capital Cost

- Because fixed costs are established at the outset of production (before the first product is made), the cost derives not only from appropriate sizing, but also from the need to distribute the cost over actual production

- Thus, a three part problem:
  - –How much equipment is required?
  - –How much does that equipment cost?
  - –How to distribute the cost of that equipment onto the production?

Capital Cost -- How Much Equipment?

▪Key Equipment Characteristic: Rate of Production

▪Another Name:
Cycle Time - Time to make one unit of production

▪Given:
- –A rate of production (or cycle time) and
- –A targeted magnitude of output (or annual production)

The number of machines can be established

▪How?

Capital Cost -- How Much Equipment?

▪The universal constraint on production: Time!

- –Targeted production volume => desired production rate
- –The amount of equipment derives from the relationship between the technical rate of production and the desired rate of production
- –If you want to exceed the rate of production of a single machine, then you need to buy more machines!

$$\# \text{ machines} = \frac{\text{desired rate of production}}{\text{machine rate of production}}$$

Capital Cost -- How Much Equipment?

- This equation can be expressed other ways:

$$\# \text{ machines} = \frac{\text{desired rate of production}}{\text{machine rate of production}}$$

$$\# \text{ machines} = \frac{\text{Required time to produce target output}}{\text{Available time to produce target output}}$$

- Sometimes, one is easier to use than the other
  - Particularly when using cycle time

Capital Cost -- How Much Equipment?

- For example:
  - Required Operating Time is
    - *Targeted production * Cycle time*
  - Available Operating Time is
    - *Total hours / yr - [Planned + Unplanned downtime]*
- Alternatively:
  - Targeted Production Rate:
    - *Targeted production / Hours available for production (as above)*
  - Machine Production Rate:
    - *1 / Cycle Time*
- Generally, the former is easier to explain

Time As Key Modeling Unifier

- The tension between available and necessary time immediately generates a workable structure for interconnection of process elements
- Time to produce underlies many elements of cost, both fixed and variable
  - –Directly:
    - *Variable: Labor & energy*
    - *Fixed: Number of machines, dies/tools*
  - –Indirectly:
    - *Fixed: Maintenance, downtime, scheduling*

- Almost impossible to avoid consideration of TIME

Engineering Basis For Cycle Time

- While cycle time can be externally set, it frequently increases the power of a model if it can be estimated endogenously

- Engineering analyses, combined with statistical tools, can supply effective tools for estimation

- Other methods, ranging from table lookup to sophisticated modeling tools, can be tied into these cost models

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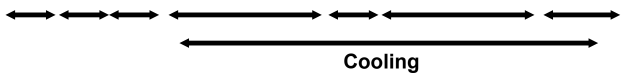
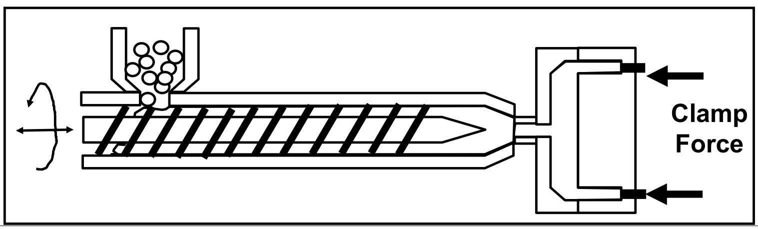
Injection Molding Cycle Time

Cycle Steps

1. Open mold 2. Advance Injector 3. Fill 4. Pack

5. Retract Injector 6. Melt Next Load 7. Open Mold





Cycle Time - Engineering Parameter

- **Working Model:**
  Cycle Time = (Fill Time) + (Cooling Time) + (Cycle Reset)

- **Cooling Time - Theoretical Determination**

$$\textit{Cooling Time} = \frac{\rho\, d^2 c_p}{\pi^2 k} \ln\left[\frac{8 \times (T_{Melt} - T_{Mold})}{\pi^2 \times (T_{Eject} - T_{Mold})}\right]$$

- **Filling Time - Varies with Part Weight**
- **Mold Cycle - Varies with Press Size, But Weakly**

★ **Assume a statistical correlation and estimate**

Cooling Time, Part Weight and Cycle Time Correlation

$$Tcyc = 1.35 \times Tcool + 0.0151 \times wgt + 8.87$$

Capital Cost --
How much does the equipment cost?

- Equipment costing can be complex
- Knowledge of the process will establish best method for estimation
- Enumeration is always preferable, but frequently may not have enough data to track all appropriate setups
- A case-specific effort

Machine Cost - Injection Molding

- Equipment Size - Function of:
  - Clamping Force
- Clamping Force - Function of:
  - Part Geometry and
  - Processing Parameters

- Empirical Relation:

$$\text{Clamp Force} = \text{Projected Area} \times N_{cavities} \times \frac{224}{\sqrt{\text{Wall Thick.}}} + 172$$

- Clamp Force Can Then Be Related To Press Cost

Correlation Between Press Cost and Tonnage

Cost = 368.82 x tonnage + 14831

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Capital Cost - How To Distribute Cost?

- Many ways to accomplish this -- formally the domain of accountants and tax specialists

- In practice, simple amortization to "annualize" costs a good starting point
  - Assumes that the allocation of capital to machines means that an "opportunity cost" must be covered
  - Alternatively, can be thought of as "paying off a loan"

- Formulas are simple and universally applied
  - Opportunity cost of capital (or interest rate)
  - Time period over which the cost is to be distributed

Capital Cost - How To Distribute Cost?

- Important Caveats:
  - Conceptual
    - *Opportunity Cost of Capital is NOT depreciation!*
    - *Opportunity Cost of Capital is NOT profit - although it may be a hurdle rate*
  - Practical
    - *Select your period appropriately - is it the lifetime of the machine, the product, or the company?*

- The formula:

Annualized Cost = Capital * $[\, r\ (1 + r)^N] \,/\, [(1 + r)^N - 1]$

Capital Cost - Per Part Calculation

- With the answer to our three questions:
  - –How many machines do I need?
  - –How much does each machine cost?
  - –How do I distribute the cost?

- We can calculate
  - –An annual cost of the equipment, assuming an opportunity cost of capital and an amortization period; and
  - –A per piece cost of capital, by dividing the annual cost by the number of pieces produced

Cost Modeling Important Concepts

- Break down problem as much as possible
- Relevant cost elements vary with question and context
- Clearly identify cost elements considered
- Calculate element cost with convenient basis
  - –Variable <==> Per Unit
  - –Fixed <==> Per Period
- Be careful of spurious precision